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MEMORANDUM REPORT ARBRL-MR-03270

USE OF HEAT INPUT TO INFER WEAR IN THE M188E2 PROPELLING CHARGE

J. Richard Ward
Irvin C. Stobie

May 1983

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) raj

Gun barrel wear technology advanced during the past decade with the advent of wear sensors or imbedded thermocouples to estimate wear of large caliber guns by firing a small number of rounds in contrast to standard wear tests in which many rounds are expended.

The wear screening techniques have been chiefly applied to unraveling the mysteries of additives. The Test and Evaluation Command (TECOM) and the Army

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20. Abstract (Cont'd):

Materiel Systems Agency (AMSAA) proposed using thermocouples and a wear test simultaneously in the M188E2 product improvement program. Pullover measurements and heat input measurements disagreed. This seemed surprising in view of the past experience with the thermal sensors in the 155-mm XM201E2 program. It was decided to review the 8-inch M188E2 wear test relying on stargauge measurements rather than the less accurate pullover measurements.

This report describes the thermal techniques, their use in the design of the 155-mm XM201 series of charges, and the results of the heat inputs and wear measurements in the 8-inch M188E2 product improvement program.

The conclusions reached were as follows:

a. Pullover and stargauge measurements made during the M188E2 wear testing differ by 0.08 mm to 0.23 mm (3 mils to 9 mils).

b. The stargauge measurements suggest that the M188E2 wear test cannot distinguish whether the Zone 9 charge is more erosive than the Zone 8 charge.

c. The 500 round wear test for the M188E2 charge sheds no more light on the relative wear between the M188E1 and M188E2 charges than the heat input tests. It is incorrect to view the M188E2 test as evidence for the failure of the thermal sensing technique to assess relative erosivity between propelling charges.

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I. INTRODUCTION

Gun barrel wear technology advanced during the past decade with the advent of wear sensors or imbedded thermocouples to estimate wear of large-caliber guns by firing a small number of rounds[1] in contrast to standard wear tests in which many rounds are expended.

The wear screening techniques have been chiefly applied to unraveling the mysteries of additives.[2] The Test and Evaluation Command (TECOM) and the Army Material Systems Agency (AMSAA) proposed using thermocouples and a wear test simultaneously in the M188E2 product improvement program. Pullover measurements and heat input measurements disagreed. This seemed surprising in view of the past experience with the thermal sensors in the 155-mm XM201E2 program. It was decided to review the 8-inch M188E2 wear test relying on stargauge measurements rather than the less accurate pullover measurements.

This report describes the thermal techniques, their use in the design of the 155-mm XM201 series of charges, and the results of the heat inputs and wear measurements in the 8-inch M188E2 product improvement program.[3]

II. ESTIMATING WEAR IN LARGE-CALIBER GUNS

Two techniques have been used the past few years to estimate wear in large-caliber guns equipped with wear-reducing additives.

The Calspan Corporation (Buffalo, NY) developed the wear sensor[4] which has a probe extending to the bore surface that is marked with a Knoop microhardness indentation. The length of the indentation is proportional to the depth. The wear sensor is removed after repeated firings and examined under a microscope to determine the wear. The sensor is usually made of gun steel, but recent tests have also used sensors made with inconel, an alloy which wears more easily than steel.

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[1] *D.S. Downs, J.A. Lannon, L.E. Harris, H. Sterbutzel, F. Vassallo, and A. Ashby, "Wear-Additive Analysis of Charges Used in Artillery Systems," Proceedings of the 1980 JANNAF Propulsion Meeting, CPIA Publication 315, Vol. I, pp. 123-150, March 1980.*

[2] *J.A. Lannon and J.R. Ward, "Workshop Report on Mechanisms of Wear-Reducing Additives," Proceedings of the 17th JANNAF Combustion Meeting, CPIA Publication 329, Vol. III, pp. 377-402, September 1980.*

[3] *L.J. Nemecek, "Product-Improvement Wear Test, M188E2 Propelling Charge," Yuma Proving Ground Firing Report No. 14616, December 1979.*

[4] *F.A. Vassallo, "Heating and Erosion Sensing Techniques Applied to the 8-Inch Howitzer," Proceedings of the 12th JANNAF Combustion Meeting, CPIA Publication 273, Vol. I, pp. 59-78, December 1979.*

Thermal measurements have been made at Calspan[5] and by Brosseau at the Ballistic Research Laboratory (BRL).[6] Imbedded thermocouples measured total heat input to the gun barrel. Calspan determines total heat input with a single thermocouple mounted near the bore surface (approximately 1 mm). The total heat input can be computed from either the maximum temperature rise or from the temperature rise at a given time after projectile exit. The method is convenient since the precise distance from the thermocouple to the bore surface need not be known. Brosseau's technique employs four thermocouples placed at different depths from the bore surface at the same axial position along the barrel. Total heat input is measured by integrating the temperature distribution at some arbitrary time (usually 100 ms after ignition).

The power of these techniques for assessing additive performance in guns is best illustrated with results from the 155-mm XM201E2 charge. The XM201E2 charge was designed to replace the M119 Zone 8 charge which had a wear life of 5,000 rounds. The XM201E2 charge differed from the M119 charge in three respects: propellant (M30 vs M6), ignition (base ignition vs center-core igniter), and additive (TiO_2-wax liner with the XM201E2).

The XM201E2 wear test in the 155-mm M185 cannon showed that the wear life was only 1,000 rounds. This was not only well below the 5,000 goal, but was less than the 1,750 round life firing the top-zone XM203E2 charge (now the Zone 8S M203 charge). Speculation as to the cause of this centered on the failure of the TiO_2-additive. It was thought that the thermal techniques could determine whether the additive was exerting any influence in the XM201E2 charge by comparing heat inputs of rounds fired minus the additive vs XM201E2 charge itself.

Subsequent testing revealed that the liner was ineffective. During the testing, it was noticed that by shortening the ignition delay of the XM201E2 charge by use of a spot of black powder in the base pad, the heat input dropped. Tests were also run with a version of the XM201E2 with a center-core igniter (XM201E1) to focus further on the role of the igniter.

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[5] *D.E. Adams and F.A. Vassallo, "Caseless Ammunition Heat Transfer, Volume III," Calspan Report No. GM-2948-Z3, April 1976.*

[6] *T.L. Brosseau, "An Experimental Method for Accurately Determining the Temperature Distribution and Heat Transferred in Gun Barrels," BRL Report No. 1740, September 1974 (AD B000171L).*

The results of the testing are summarized in Table 1.[7,8] The conclusions about the additives were:

a. the additive was not effective in reducing the total heat input of the XM201E2 charge.

b. the additive was effective in the XM203E2 and XM201E1 charges.

c. the additive in the XM201E2 charge worked with a black powder igniter.

d. the M119 charge would still produce less erosion than the XM201E2 charge with black powder.

Subsequent proving ground tests verified each conclusion.[9]

Based on this experience, the thermal measurments seemed to be a powerful tool for the charge designer, particularly for the product-improvement test of the 8-inch M188E2 charge. The product improvement consisted of the replacement of M30A2 propellant with M31E2 propellant with a concomitant 400K reduction in flame temperature in order to reduce the muzzle flash. The only restriction regarding wear was that the new charge with M31E1 propellant (M188E2) would be no more erosive than the M188E1 charge, although it was fully expected that some increase in wear life would accrue with the M31E2 propellant. The evaluation agencies (TECOM and AMSAA) proposed that both heat inputs and a limited wear test be done.

Heat input measurements were performed by the Large Caliber Weapons System Laboratory (LCWSL) and Calspan at the Naval Surface Weapon Center's Dahlgren Laboratory.[10] Because of concern over unburned fragments of liner

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[7] *F.A. Vassallo, "An Evaluation of Heat Transfer and Erosion in the 155-mm M185 Cannon," Calspan Technical Report No. VL-5337-D-1, July 1976.*

[8] *J.R. Ward and T.L. Brosseau, "Effect of Wear-Reducing Additives on Heat Transfer in the 155-mm M185 Cannon," BRL Memorandum Report No. 2730, February 1977 (AD A037374).*

[9] *T.G. Hughes, "DT II Test of Propelling Charge, 155-mm, XM201E5," APG Firing Record No. P-82646, July 1977.*

[10] *D.S. Downs, J.A. Lannon, L.E. Harris, H. Sterbutzel, F. Vassallo and A. Ashby, "Wear-Additive Analysis of Charges Used in Artillery Systems," Proceedings of the 1980 JANNAF Propulsion Meeting, CPIA Publication 315, Vol. I, pp. 123-150, March 1980.*

TABLE 1. HEAT INPUT RESULTS FROM 155-mm XM201E2 INVESTIGATION

Propelling Charge	Modification	Heat Input, J/mm*	Heat Input, J/mm^2**
XM203E2	No liner	793	-
XM201E2	No liner	824	1.329
XM201E1	No liner	750	-
XM201E2	No liner, black powder	764	-
XM201E2	-	813	1.278
XM201E1	-	701	-
XM203E2	-	702	1.119
XM201E2	Black powder	712	1.231
M119	-	677	1.138

*Clean-out round after each test round - Brosseau's technique.

**Average of five shots - Calspan technique.

being left in the chamber,[11] tests were conducted with various modifications to the Zone 8 liner. The results of the heat input measurements are summarized in Table 2. Unburned fragments remained when additive was used in the Zone 8 increment, so the version with no liner in Zone 8 was the preferred design.[3]

The results in Table 2 predict that the Zone 8 and Zone 9 M188E2 charges will be less erosive than their M188E1 counterparts with M30A2 propellant, even with the TiO_2-wax liner removed from the Zone 8 M188E2 charge. By analogy with the 155-mm results, it was also predicted that the new Zone 8 M188E2 minus an additive could be as erosive as the Zone 9 charge. This situation is equivalent to the XM201E2 charge and the XM203E2 charge for which the lower zone charge (XM201E2) had the shorter wear life because the additive was ineffective.

Round limitations for the wear test necessitated that only five hundred rounds could be fired, so the firing was done in an 8-inch cannon (M201) in which the chromium had already chipped away in the commencement of rifling region. The test was equally divided between Zone 8 and Zone 9 M188E2 charges.[4] The pullover measurements taken during the firing were the basis for interpreting results which are summarized in Table 3. By comparison, the wear for the Zone 8 and Zone 9 M188E1 charges are 1.2 μ/shot and 0.4 μ/shot, respectively. The wear test with the new charges corroborated the heat input results that wear was no worse when M31E2 propellant replaced M30A2 propellant in either Zone 8 or Zone 9. The wear test results as determined with the pullover measurements did not show that the Zone 8 M188E2 charge without TiO_2-wax additive was as erosive as the Zone 9 charge, which cast doubt on the capability of the thermal technique.

III. REVIEW OF STARGAUGE MEASUREMENTS

Table 4 lists the stargauge results at various axial stations. One sees that the wear for the Zone 9 charge changes from 0.30 mm (12 mils) to 0.15 mm (6 mils) based on the stargauge, while the wear for the Zone 8 charge remains 0.10 mm (4 mils). The stargauge measurements suggest that the total wear is too small for judgements on the relative erosivity of the Zone 8 and Zone 9 charges. One would certainly not conclude the Zone 9 charge is two to three times more erosive than the Zone 8 charge. One would conclude from the stargauge results that the M188E2 charges are less erosive then the M188E1 charges with M30A2 propellant, but that too little wear was recorded to determine relative erosivity between Zones 8 and 9 of the new M188E2 charge. Thus, the wear test properly viewed with the stargauge results provided no more information than the thermal technique, and the results between the wear test and thermal method are consistent.

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[11] *D.S. Downs and L.E. Harris, "Relationship of Residue Formation to Wax Used in M203 Propelling Charge Liners," ARRADCOM Technical Report ARLCD-TR-79042, December 1979.*

TABLE 2. HEAT INPUTS FOR 8-INCH M188E1 AND M188E2 PROPELLING CHARGES*

Charge	Propellant	Zone 8 Liner Modification	Heat Input,** J/mm^2 Zone 8	Zone 9
M188E1	M30A2	none	2.02	2.14
M188E2	M31E1	flap***	1.60	1.61
M188E2	M31E1	half as long as liner in M188E1 Zone 8	1.73	1.63
M188E2	M31E1	liner removed	1.87	1.68

*All charges conditioned to 294 K.

**Average heat input for five rounds.

***Unburned residue left in chamber.

TABLE 3. PULLOVER MEASUREMENTS FROM EIGHT-INCH M188E2 WEAR TEST*

Tube Round No.	Test Rounds Fired	Zone	Wear,** mm	(mils)
1161	0	9	1.60	(63)
1214	5	9	1.68	(66)
1299	138	9	1.78	(70)
1401	240	9	1.91	(75)
1411	250	9	1.91	(75)
1461	0	8	1.96	(77)
1536	75	8	2.01	(79)
1626	165	8	2.06	(81)
1711	250	8	2.06	(81)

*Pullover measurements made at 1.17 m (46 inches) from rear face of tube (RFT).

**Vertical land diameter change above basic measurement of 8.000 inches (203 mm)

TABLE 4. STARGAUGE LAND WEAR MEASURED NEAR THE COMMENCEMENT OF RIFLING DURING M188E2 WEAR TESTING

Axial Location, M (in), RFT		Vertical, mm (mils)		Horizontal, mm (mils)	
		Zone 9*	Zone8**	Zone 9*	Zone 8**
1.160	(45.65)	0.08 (3)	0.10 (4)	0.15 (6)	0.0 (0)
1.163	(45.80)	0.15 (6)	0.13 (5)	0.15 (6)	0.03 (1)
1.170	(46.05)	0.15 (6)	0.10 (4)	0.15 (6)	0.08 (3)
1.17***	(46)	0.31 (12)**	0.10 (4)***		
1.182	(46.55)	0.23 (9)	0.18 (7)	0.20 (8)	0.25 (10)

*Wear from rounds 1161 to 1411.

**Wear from rounds 1461 to 1711.

***Pullover measurements.

IV. CONCLUSIONS

1. Pullover and stargauge measurements made during the M188E2 wear testing differ by 0.08 mm to 0.23 mm (3 mils to 9 mils).

2. The stargauge measurements suggest that the M188E2 wear test cannot distinguish whether the Zone 9 charge is more erosive than the Zone 8 charge.

3. The 500-round wear test for the M188E2 charge shed no more light on the relative wear between the M188E1 and M188E2 charges than the heat input tests. It is incorrect to view the M188E2 test as evidence for the failure of the thermal sensing technique to access relative erosivity between propelling charges.

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